HYDROGEN

“*Where are we now?*”
“*Where is the focus?*”

27th April 2021

Event supported by : SEAS Sustainable Energy Association of Singapore

Summary

We learned from our three eminent speakers, Stephen Harrison, Martin Lambert and Marc Allen, that many energy industry professionals worldwide, whether from conventional, renewables or evolving energy sector backgrounds now believe that Hydrogen is critical to the world's ability to reach net-zero by mid-century, as neither renewable energy nor the pivot towards maximising electrification alone can achieve that target, especially in hard-to-abate sectors like heavy industry and the high horse-power transportation sector.

However, there are "many bullets in the gun" and whilst hydrogen may replace oil as the primary fuel in various spheres of life as it is easy to store in large quantities, and provides a viable alternative fuel, for uses that are costly to electrify or cannot be electrified. We also heard that, Ammonia and Methanol are much more advanced than is commonly understood.

Our speakers explained that in the future, green hydrogen will become the undisputed leader among renewable energy sources generated from surplus solar, wind and other sources such as hydro and, potentially a revitalisation of nuclear. Furthermore, this surplus power will be required to supply the growing market, which is estimated to require some ten times the current production capacity by 2050, does not exist today and is unlikely to do so for some time to come. In a regional context, we heard that Australia could become Asia's big battery.

The Panel

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Hydrogen: Clean and powerful energy

Understanding hydrogen's role in the energy transition

Stephen B. Harrison

The Energy Institute
27 April 2021

Link for registration:
https://www.energyinst.org/whats-on/search/events-and-training?meta_eventId=2104SING

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Applications

Hydrogen – Clean and powerful energy

NexantECA

Stephen B. Harrison

April 2021

Applications - Agenda

Hydrogen as one of many solutions to decarbonise transportation, domestic energy applications, electricity grid management and heavy industry: A look at it's potential to displace coal, oil and gas.

Early-stage deployment of hydrogen at scale: no-regrets use cases and early adopters

Hydrogen as one of many solutions to decarbonise the energy sector and industry

Hydrogen – Clean and powerful energy

NexantECA

Stephen B. Harrison

April 2021

Ammonia shipping as a bulk cargo is established

Ammonia is in development as a marine fuel

Methanol shipping as a bulk cargo is established and methanol is an established marine fuel

Liquid hydrogen shipping as a marine cargo is being piloted from Australia to Japan – HySTRA, HESC (Suiso Frontier)

Hydrogen powered shipping - cruise liners in eco-sensitive areas (eg Fjords in Norway) are likely to lead the way, others may follow

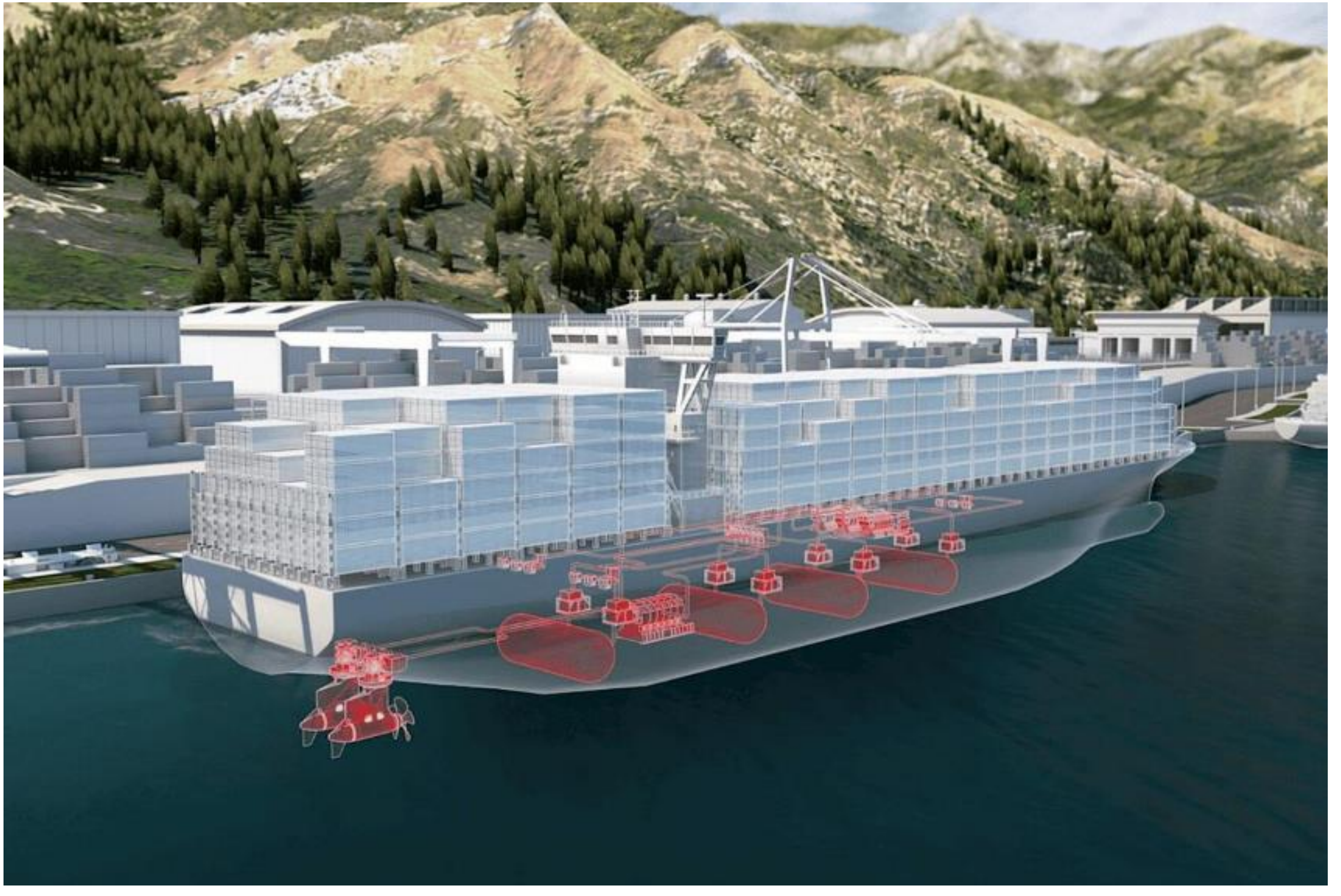

Image copyright ABB

As with cars and trucks, batteries are also an option as a propulsion energy source

Image copyright Yara

Decarbonisation is key – low carbon hydrogen is essential for the future

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World-scale methanol facility
Petronas, Labuan Malaysia

Qatar Fuel Additives Company Limited
SMR flue gas, methanol production, 500 tons per day CO2 capture

Image courtesy Mitsubishi Heavy Industries

Hydrogen / ammonia / urea value chain
Typically SMR fed with natural gas

Gulf Petrochemical Industries Co, Bahrain
SMR flue gas, ammonia / urea, 450 tons per day CO2 capture

Image courtesy Mitsubishi Heavy Industries

Naphtha / refinery-gas fed SMR for refinery hydrogen applications
Carburos Metálicos, Repsol Refinery, Tarragona, Spain

Image courtesy of APCI Inc

Carbon capture plant recovering CO2 from the SMR flue gas
Carburos Metálicos, Repsol Refinery, Tarragona, Spain

Image courtesy of APCI Inc

Biomass to biogas to biomethane, then SMR to green hydrogen with BECCS – A Carbon-negative process

10MW singe-stack AEC Electrolysis System, can make green hydrogen when using renewable electrical power

Thermolysis of MSW and RDF to produce hydrogen-rich syngas
Waste to energy for the circular economy

Early stage deployment of hydrogen at scale: no-regrets use cases and early adopters

Hydrogen – Clean and powerful energy

Stephen B. Harrison

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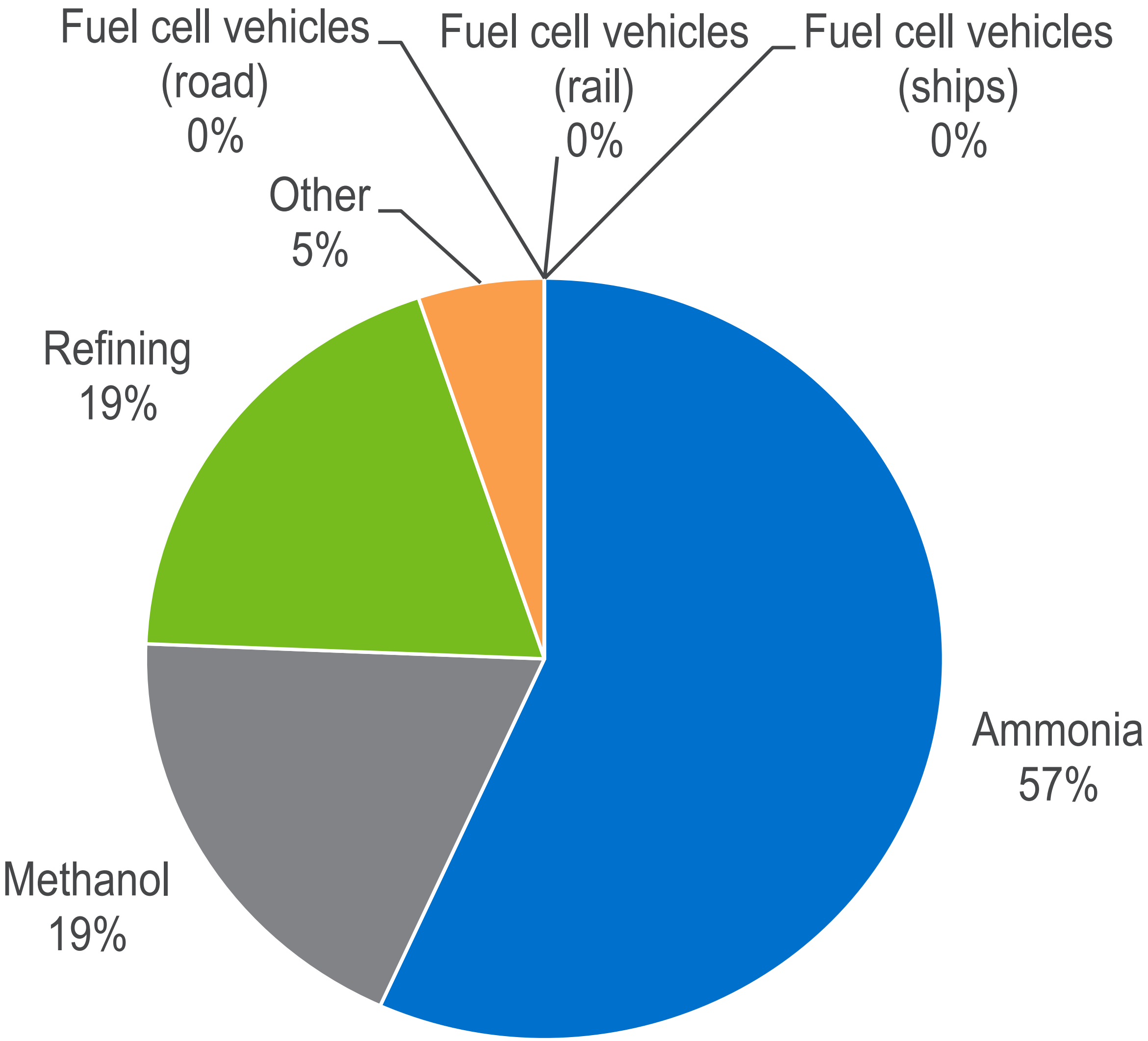
Hydrogen is mostly consumed as an industrial gas in ammonia and methanol production, and refining



Where green and blue hydrogen can substitute grey – off takers exist, risks are low

Ammonia production accounts for more than 50% of global hydrogen consumption

SMR plus ATR for the world's largest methanol plant Kaveh, Iran, under construction

Image credit: International Thermal Technology S.p.A

Turkmengaz gas to methanol to gasoline, Ashgabad
Catalytic autothermal reforming of natural gas, startup in 2021

Photo courtesy of Haldor Topsoe

Multiple new SMRs – one of the world's largest hydrogen facilities
Clean Fuels Project, KNPC MAB & MAA refineries, Kuwait

Image credit: International Thermal Technology S.p.A

Hydrogenation of oils to fats, eg Sunflower oil to margarine and biofuels hydrogenation

Float-glass making to generate a reducing atmosphere around the molten tin-bath

Power storage and mobility applications – some will go to hydrogen, batteries will also play a huge role

Stationary fuel cells have a range of different applications in remote and backup power: hospitals, military, data-centres, off-grid…

Heavy mining machinery, excavators and earth movers

Hydrogen powered train – diesel replacement CORDIA iLINT

Hydrogen buses - many are already in operation

Image copyright Hyundai

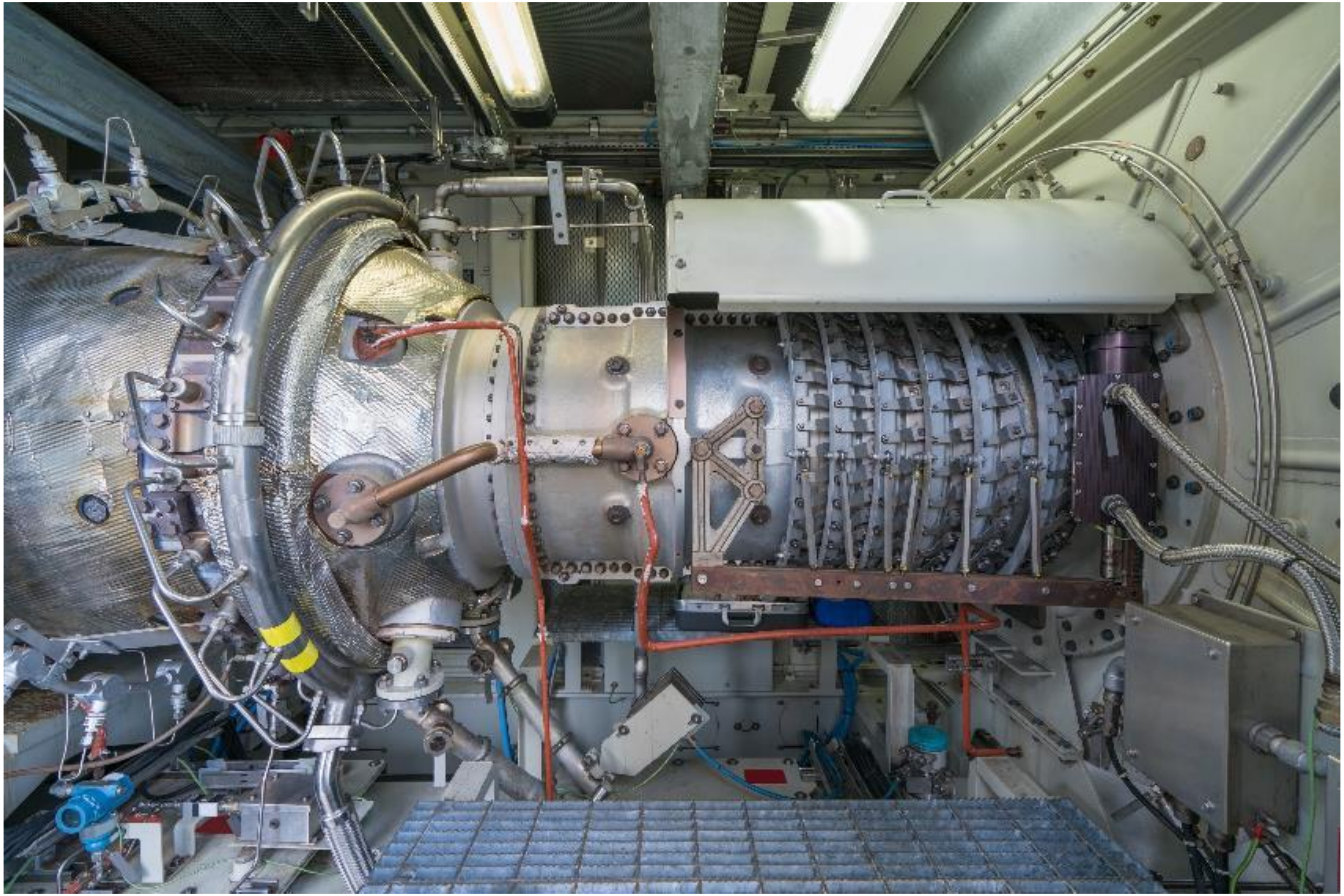
Hydrogen fuelling station (HFS) for fuel-cell powered vehicles Germany has a network of more than 90

(Indoor) material handling is one of the most successful non-traditional applications for hydrogen

Image copyright Toyota

What next for hydrogen and hydrogen derivatives?
Emerging use cases to displace fossil fuels

Ammonia can be burned on gas turbines (pure, or blended with natural gas) for power generation



Ammonia can be added to coal on thermal power stations to reduce their CO2 emissions footprint

Direct reduction of iron – hydrogen to replace coke as a reducing agent

April 2021

Heating – gas grid injection and admixing

Synthetic aviation fuels, or hydrogen powered aircraft

Closing Remark
Not “or”, but “and”

Hydrogen – Clean and powerful energy

NexantECA

April 2021

Want to know more?
NexantECA Training – Hydrogen, Clean and Powerful Energy

Day 1

Sources
Hydrogen worlds

- Introduction
- Grey hydrogen
- Blue hydrogen
- Green hydrogen
- Other sources

Day 2

Supply chain and economics

- Ammonia
- Methanol
- Hydrogen supply chain
- Economic assessment

Day 3

Demand pathways and regulation

- Demand growth
- Conventional uses
- Growth scenarios
- Regulation and politics

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THE OXFORD INSTITUTE FOR ENERGY STUDIES

Hydrogen in Europe: Where are we now, where is the focus?

Energy Institute Asia Webinar, 27th April 2021

Martin Lambert
Senior Research Fellow

Hydrogen in Europe – approaches vary by country

- Recent paper compares 6 major gas-consuming countries:
  - France
  - Germany
  - Netherlands
  - Italy
  - Spain
  - United Kingdom
- National hydrogen strategies published by 4 countries, while Italy and UK to finalise soon
- Different approaches in different countries (in contrast with natural gas market?)
- Policy approaches still under development
- Very wide range of demand forecasts in all markets even to 2030 and certainly to 2050
- Supply approaches similarly variable

Hydrogen Strategies and Policy Drivers vary by country

Publication	June 2018 & Sept. 2020	June 2020	March 2020	April 2020	Sept. 2020 (SNAM)	1H 2020 (CCC)
H2-Technology	●	●	●	●	●	●
Technology Leadership	◕	●	◕	◑	◔	◕
Hydrogen for export	◑	○	◔	●	○	◔
Imports of hydrogen	○	●	◔	○	◕	○

Source: Authors' analysis of country publications

- **Italy published "preliminary guidelines for a national hydrogen strategy" Dec 2020 – final version expected soon**
- **UK "Ten Point Plan for a Green Industrial Revolution Nov 2020" – Hydrogen strategy expected by mid-2021**
- **Green hydrogen long term goal, with blue hydrogen (UK / NL), nuclear powered hydrogen (France) as stepping stones**
- **Contrasting views on potential cross border trade**

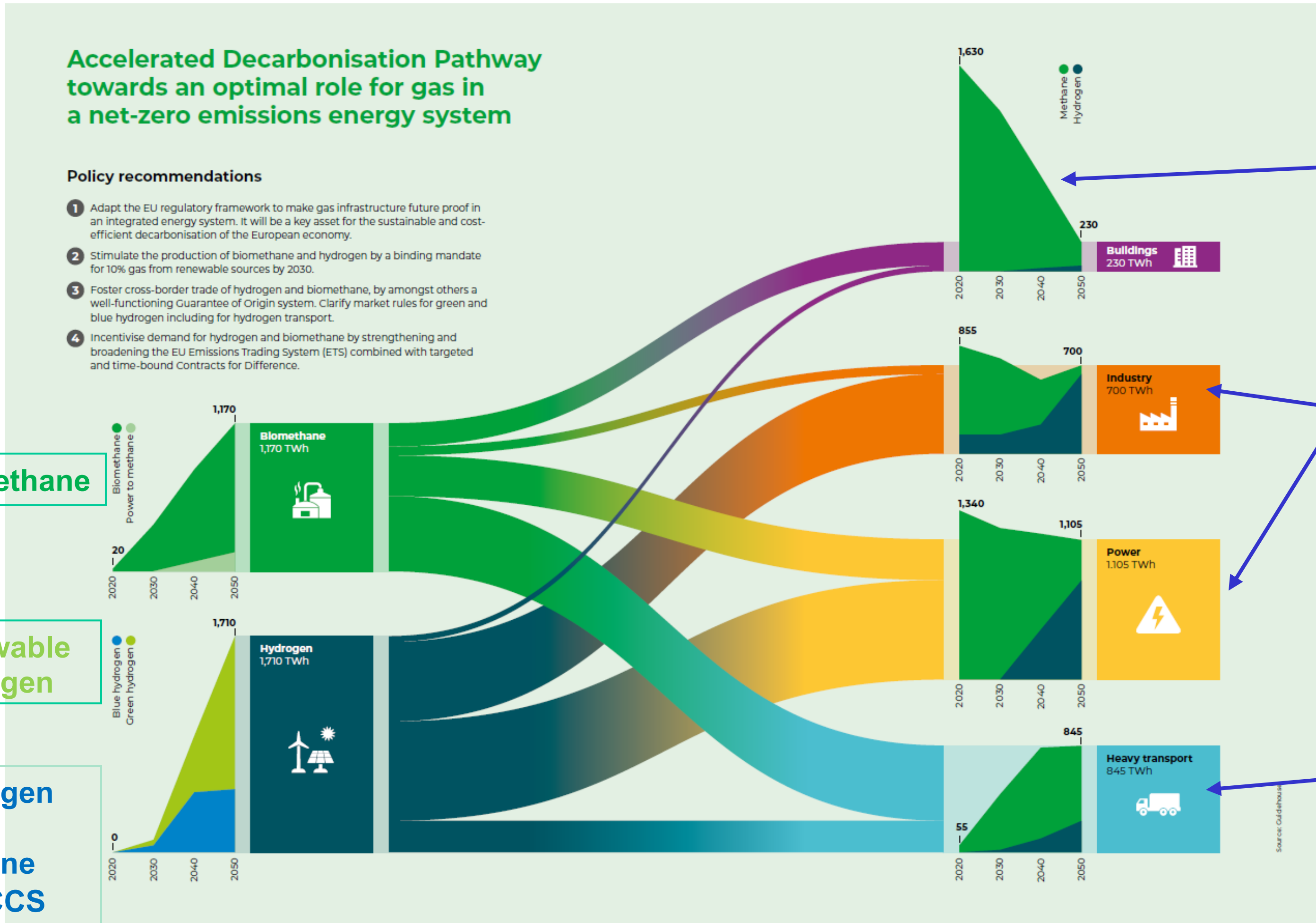
Hydrogen in context of other gaseous fuels

No role for unabated natural gas in Europe by 2050: Growing consensus on significant role for renewable gases

Biomethane

Renewable Hydrogen

Hydrogen from Methane with CCS



Significant decline of methane use in buildings – hybrid heat pumps?

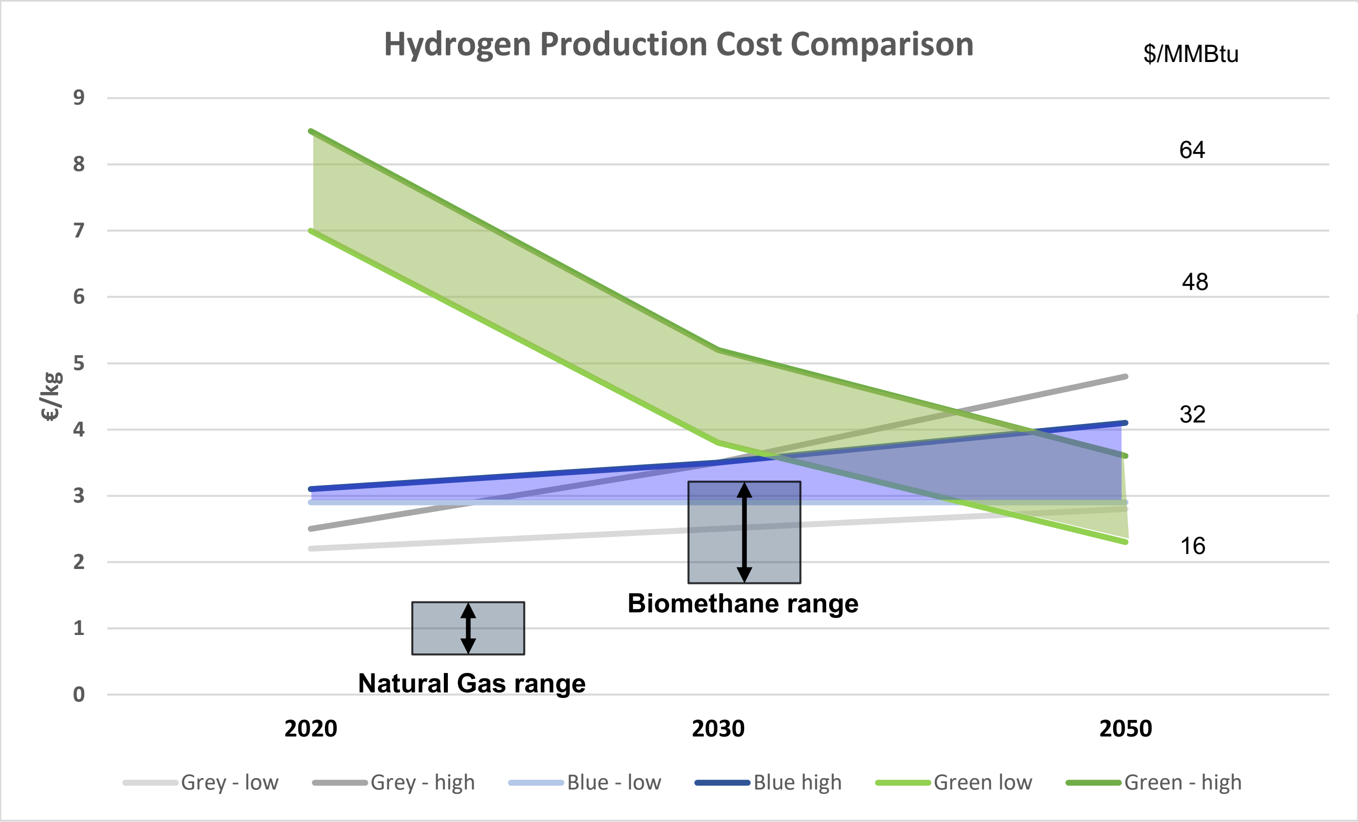
Industrial use and balancing power grid shifts from methane to hydrogen

Overoptimistic view of potential role of gas in transport?

Current policy tends to support renewable gas in transport

Source: Navigant Gas for Climate, Decarbonisation Pathways April 2020

Green and Blue hydrogen costs expected to converge …but at a premium to methane



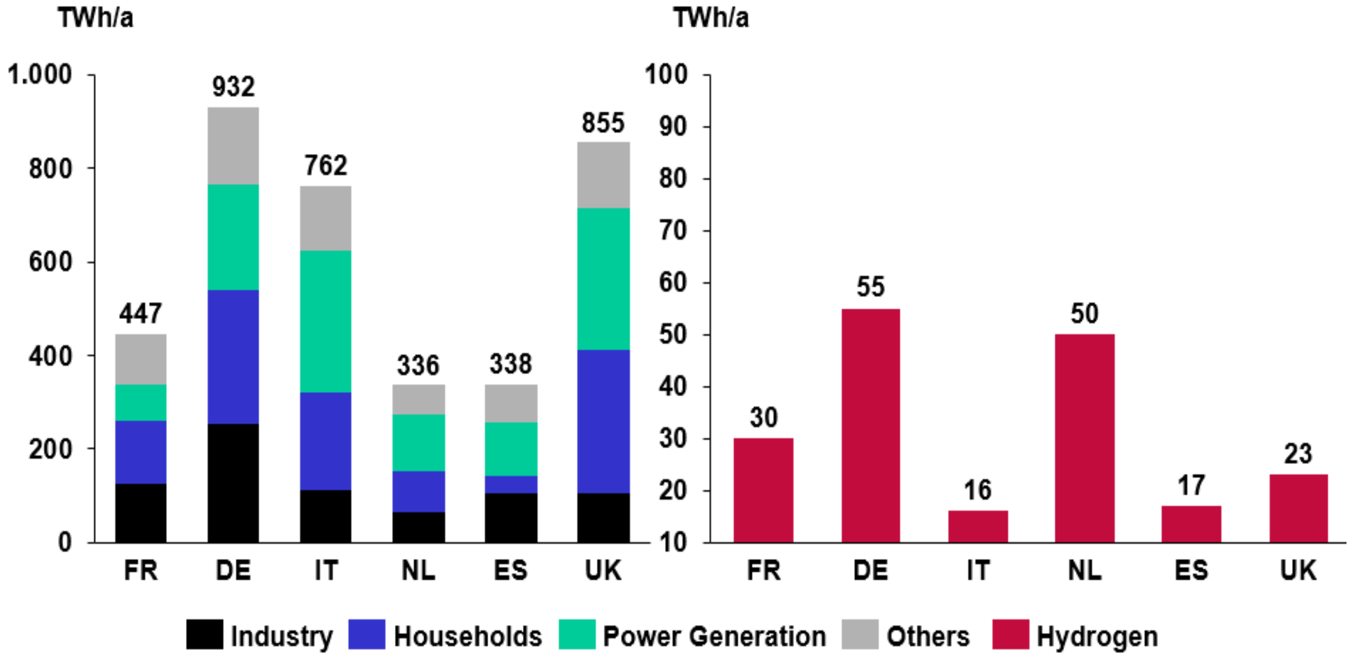
- Green hydrogen currently small scale and high cost
- Blue hydrogen relatively small premium over Grey

"Grey" = SMR without CCS
"Blue" = SMR with CCS
"Green" = Electrolysis from renewable energy

1 EUR/kg =~25 EUR/MWh
= ~ 8$/MMBtu

Source: OIES analysis, Zero Emissions Platform Nov 2019, includes assumed carbon price

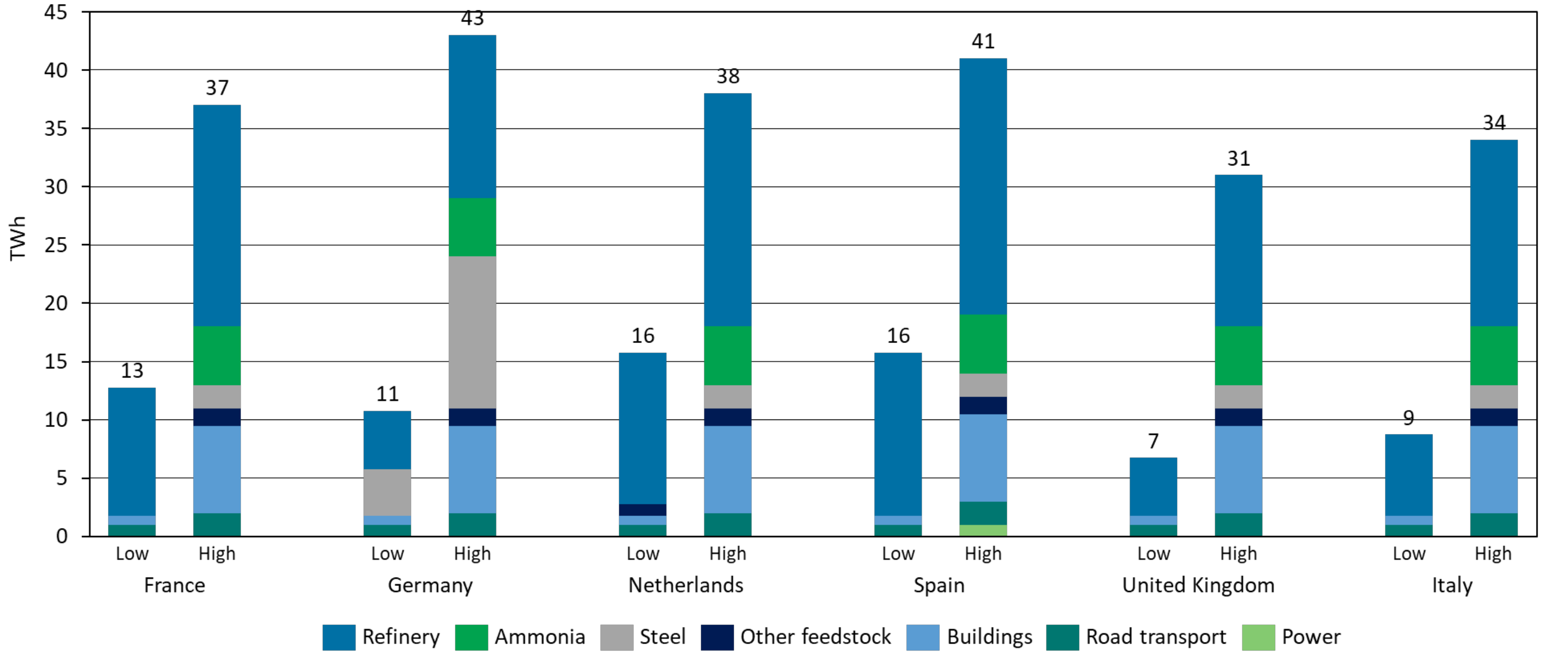
Significant hydrogen demand already exists



Source: Eurostat / Authors' analysis

- … particularly in Germany and Netherlands, but an order or magnitude less than current natural gas demand
- Nearly all in industrial sector: oil refining, petrochemicals, ammonia for fertiliser
- >95% produced from fossil fuels (either integrated with oil refining or from Steam Methane Reforming of natural gas).
- ~10 tonnes CO_2 per tonne hydrogen

Incredibly wide range of demand forecast for 2030 – just 9 years away!

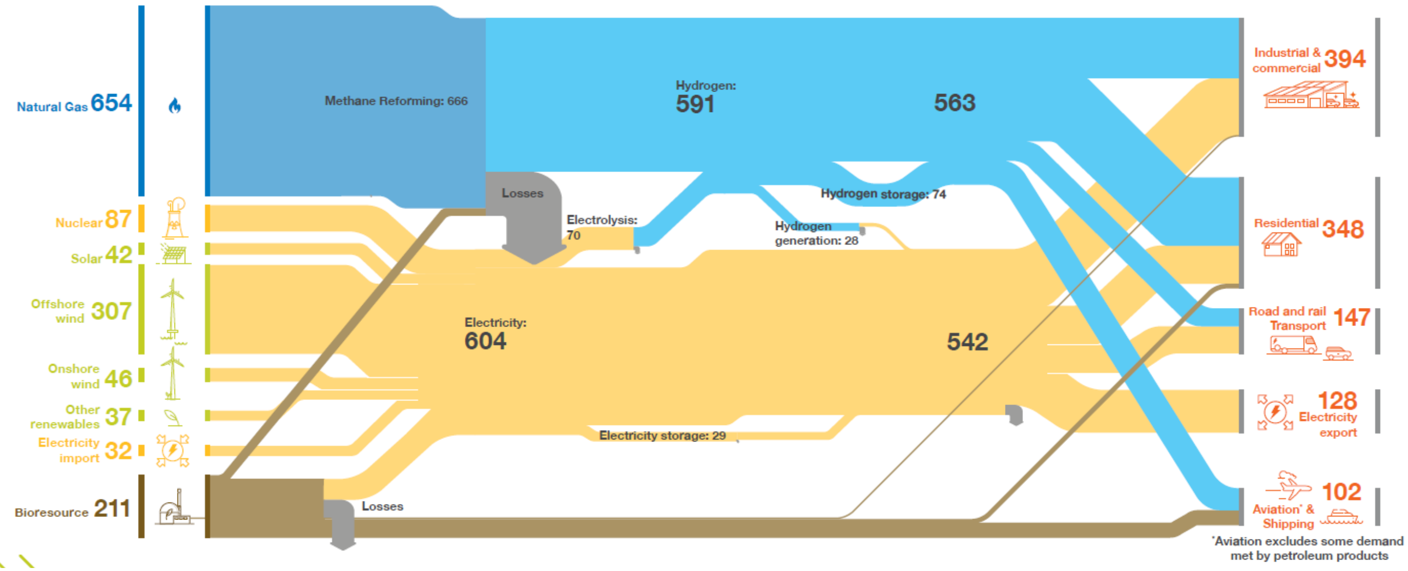


Source: authors' analysis of FCH JU (Aug 2020)

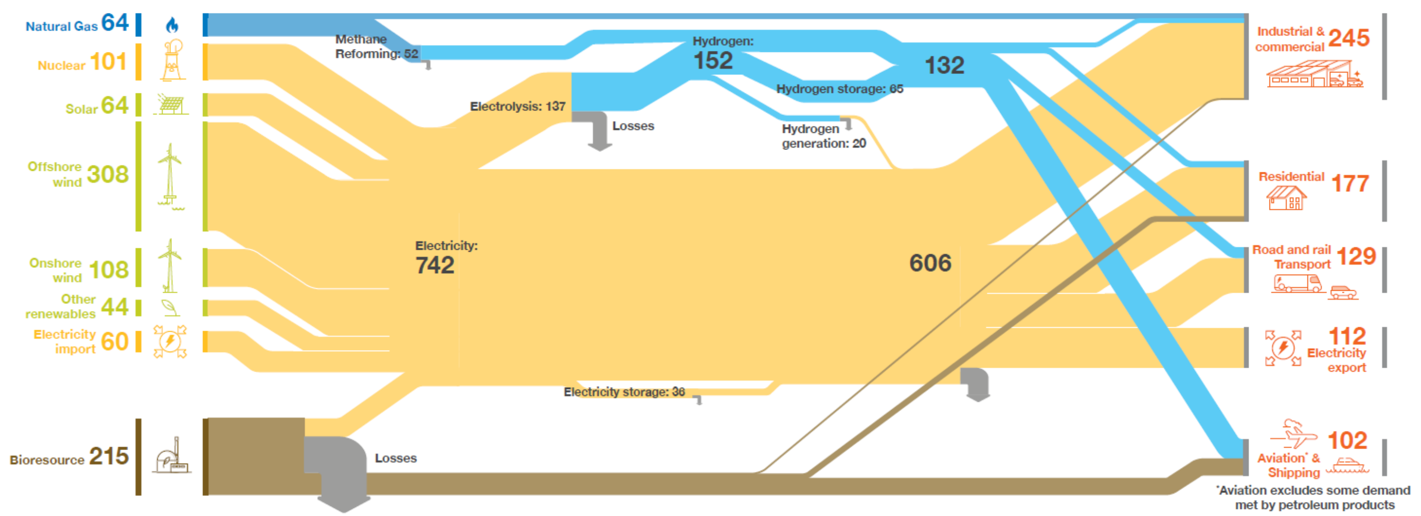
- **Wide range driven by varying assumptions of hydrogen penetration by demand sector (e.g. buildings 0.75 to 7.5% penetration, transport 1 to 2%, ammonia 0 to 5%)**
- **Even top of range is not significantly more than current grey hydrogen demand**
- **Volume of demand will not constrain low-carbon hydrogen supply**
- **Priority to create viable business cases for large scale low-carbon hydrogen production (1GW capacity at 3000 full load hours = 3TWh per year)**

By 2050 policy / consumer choices can drive very diverse outcomes: UK example

Source: National Grid Future Energy Scenarios (July 2020)

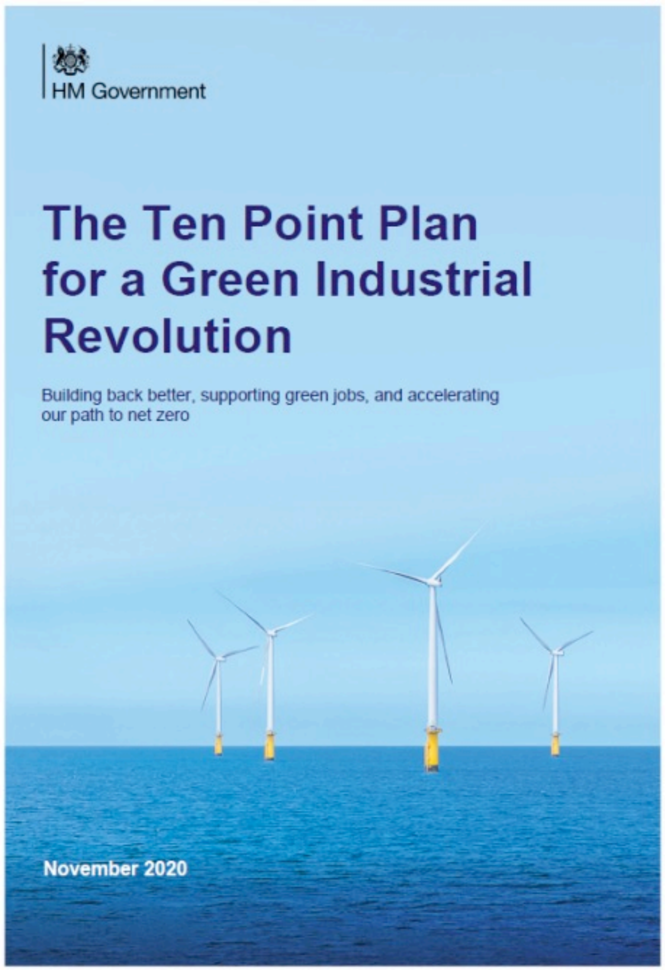


System Transformation



Consumer Transformation

UK has ambitious plans to reach Net Zero – with hydrogen playing a role in several areas



Point 1: Advancing Offshore Wind

Point 2: Driving the Growth of Low Carbon Hydrogen

Point 3: Delivering New and Advanced Nuclear Power

Point 4: Accelerating the Shift to Zero Emission Vehicles

Point 5: Green Public Transport, Cycling and Walking

Point 6: Jet Zero and Green Ships

Point 7: Greener Buildings

Point 8: Investing in Carbon Capture, Usage and Storage

Point 9: Protecting Our Natural Environment

Point 10: Green Finance and Innovation

Hydrogen Market Model not yet clear

- Government policy needs to drive move away from fossil fuels – otherwise no commercial business case
- Similarities to early days of gas / LNG business?
  - Large infrastructure investments paid back over several years
  - Long-term contracts underpin revenue stream (with take or pay?)
  - Investments by joint ventures to spread risk
  - Revenue from creditworthy entities (governments / large utilities)
  - Often direct negotiation with governments
- Additional risks to be managed, e.g.:
  - Uncertain carbon pricing – who pays? Carbon Contracts for Differences?
  - Revenue stream dependent on government policy – stability guarantees?
  - Subsequent projects likely to be significantly lower cost – auctions for government support?
  - Long-term risk of CO_2 sequestration – low probability / high impact?
- Little similarity with liberalised (well-established) gas markets
- Too many options?

Thank You! / Q&A

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engeco

Hydrogen in APAC
Where to from here?


“Hydrogen today is enjoying unprecedented momentum. The world should not miss this unique chance to make hydrogen an important part of our clean and secure energy future”
— Dr. Fatih Birol, Executive Director – International Energy Agency

Three focus areas

Supply side

The next big export opportunity for the lucky country?

Demand side

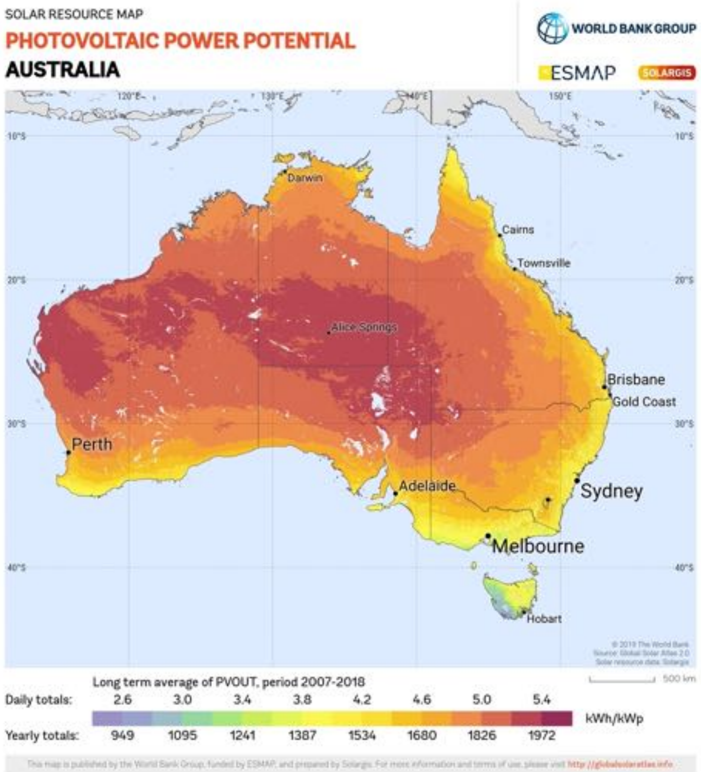
水素、アンモニア、両方？

Equipment

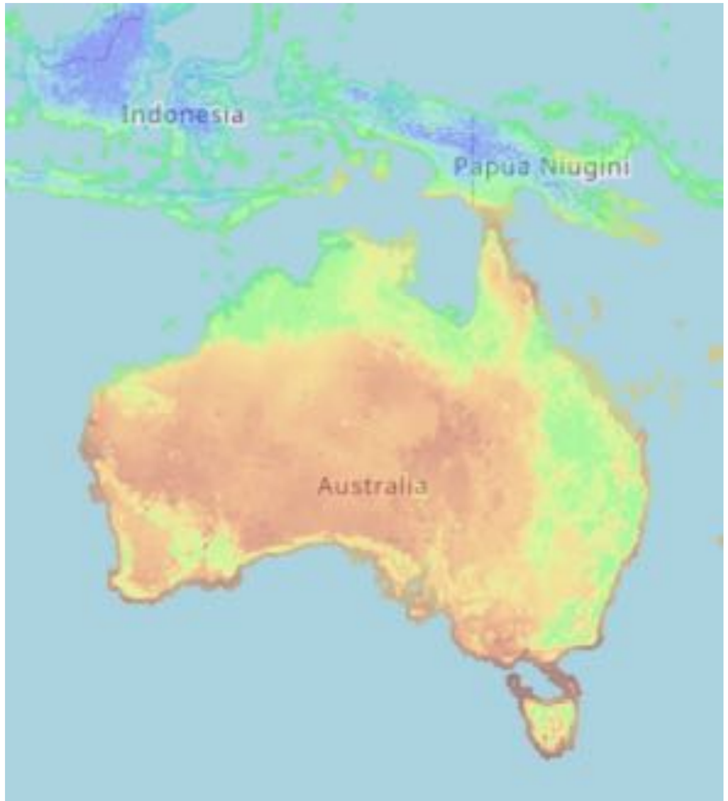
Opportunities and impacts of scaling up manufacturing capacity

SUPPLY SIDE

- Australia looking to take advantage of abundant renewable energy and aims to export excess production



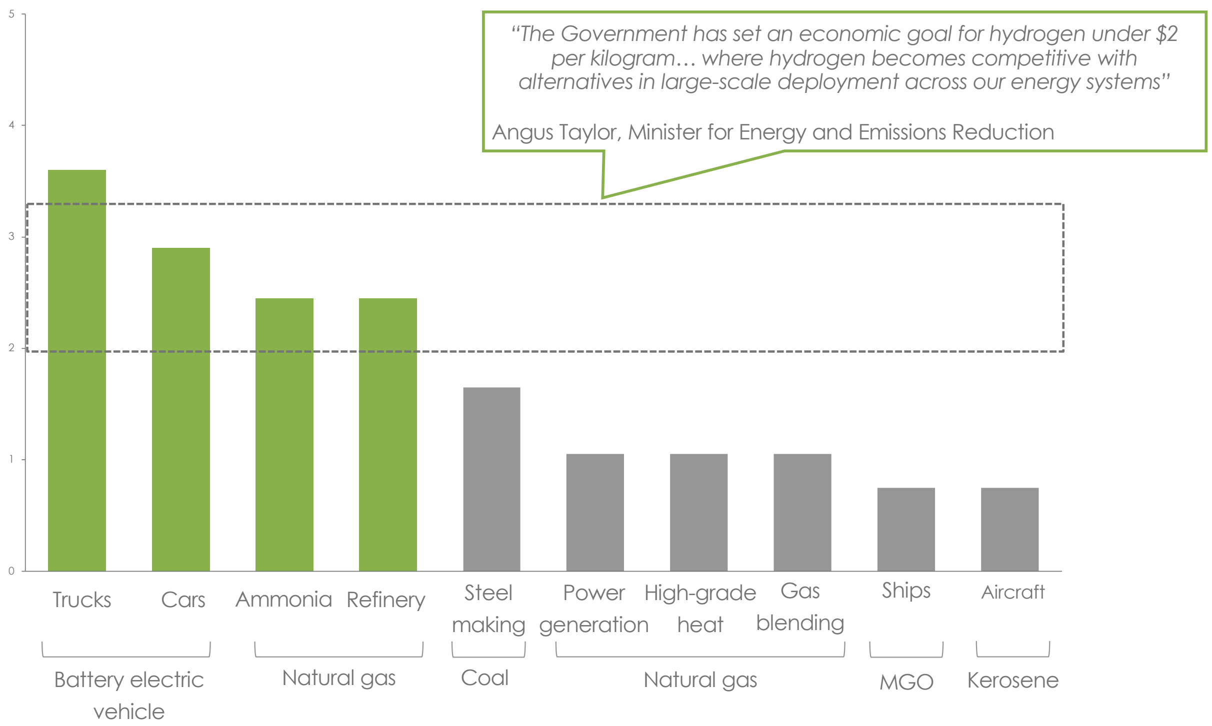
- Good overlap of strong wind and solar resources – potential for generation of RE across central Australia
- If hydrogen is to be targeted, transportation modes are key, as is trade-off between cost of transmission vs. piping hydrogen



AUSTRALIA HYDROGEN ROADMAP

At $2/kg (AUD), hydrogen is cost-competitive against alternative technologies for heavy and light vehicles, ammonia production and refineries…

Cost of alternative technologies vs hydrogen for various applications, AU$/kg H2, 2030



- Australia developed both a hydrogen strategy (2018) and subsequent hydrogen roadmap (2019)
- Export features heavily – hydrogen production cost would need to be $2/kg to be competitive for export (CSIRO estimate)
- Both green and blue hydrogen are under consideration

Additional funding for CCS and hydrogen just announced an additional $539M in the May budget (on top of $120M last year)

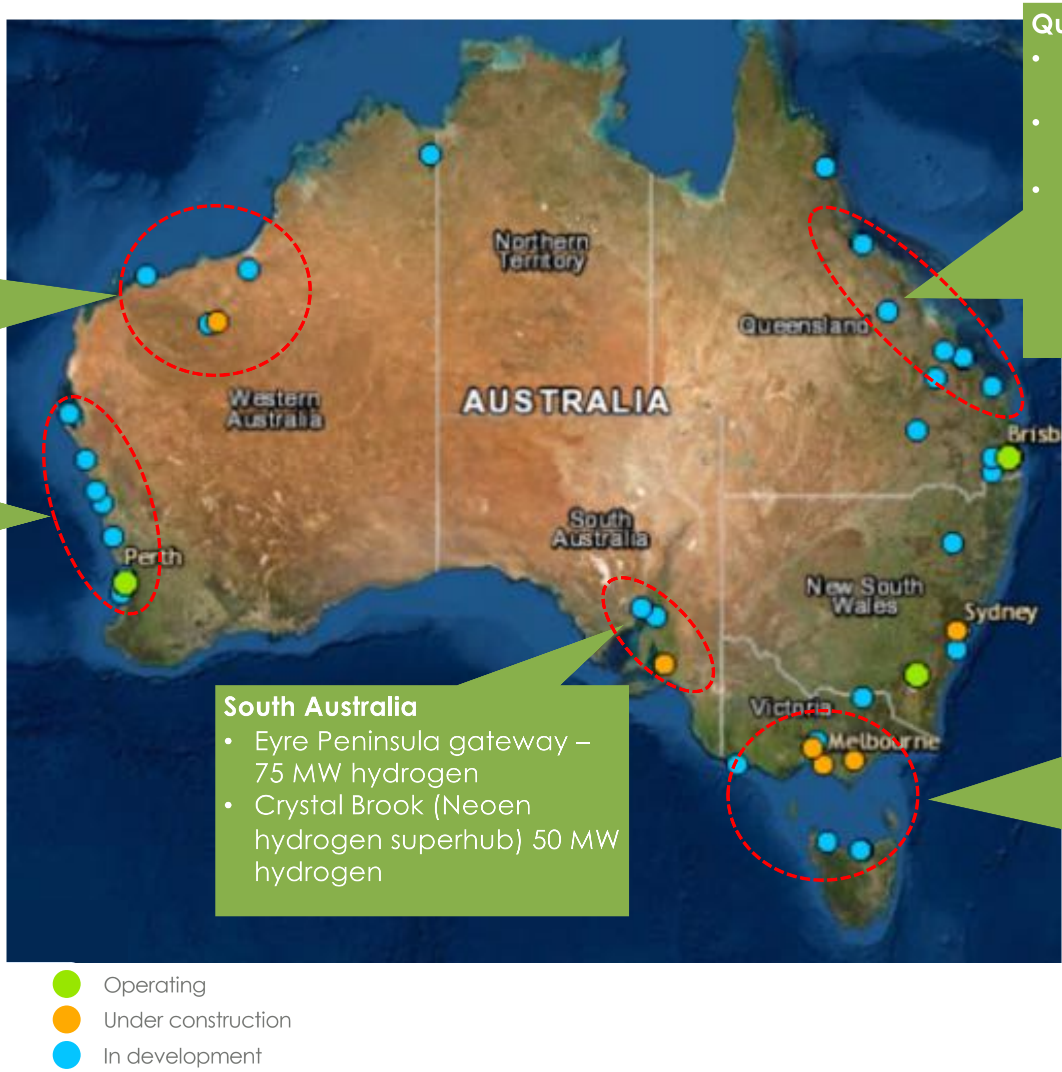
Projects in (mostly) early stage

Pilbara region

- Asian Renewable Energy Hub - 23 GW green hydrogen and ammonia (26 GW solar and wind)
- Yara renewable ammonia – 10 MW green ammonia
- Christmas Creek – 1.4 MW refuelling station

Mid-west region and Perth

- Geraldton export scale renewable investment – 30 MW hydrogen
- Arrowsmith hydrogen project – 160 MW solar and wind + hydrogen for export
- Hazer demonstration plant – biogas cracking



Queensland

- Range of projects under investigation
- Dyno Nobel/Incitec Pivot project – 160 MW
- Bundaberg hydrogen hub – 80 MW hydrogen

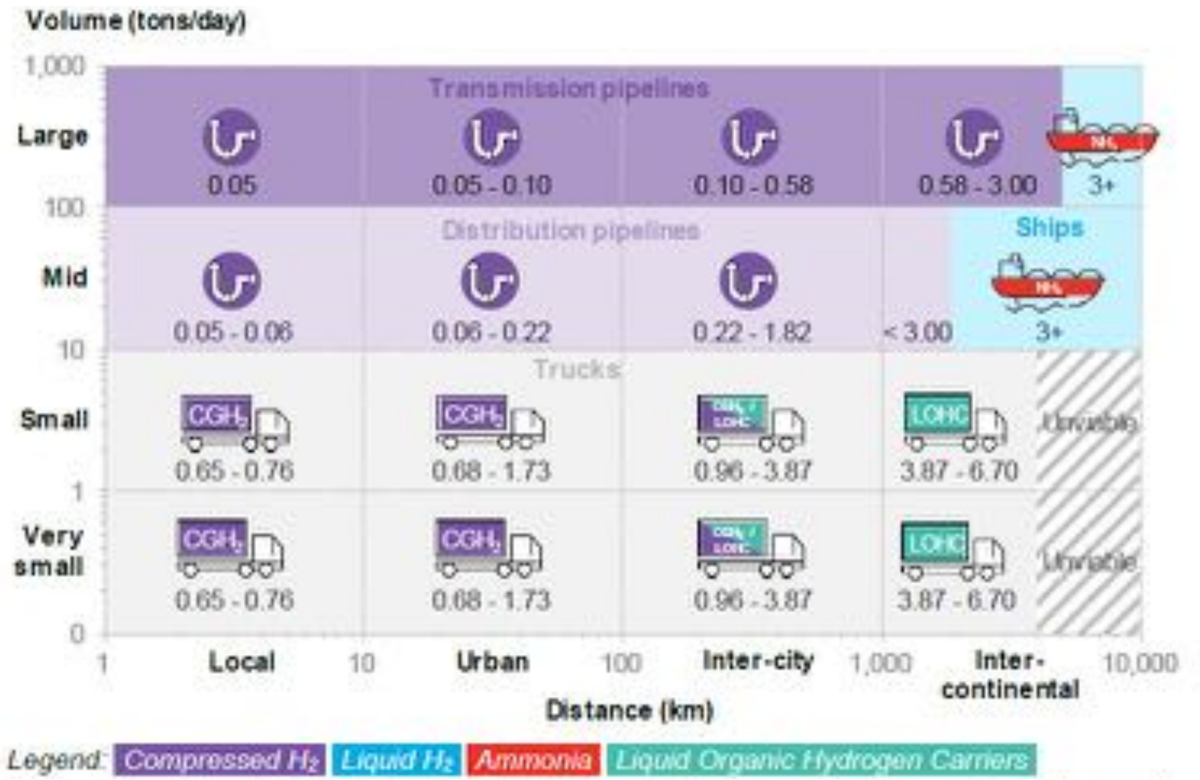
South Australia

- Eyre Peninsula gateway – 75 MW hydrogen
- Crystal Brook (Neoen hydrogen superhub) 50 MW hydrogen

Victoria and Tasmania

- Brown coal gasification and export of liquid hydrogen – Construction nearing completion (will need CCS!)
- Grange Resources (TAS) – 100 MW hydrogen
- Bell Bay (TAS) – 10 MW hydrogen

TRANSPORT REMAINS CHALLENGING



- International shipping modes being investigated
- Ammonia viable now – conversion back to hydrogen could be an issue
- Methanol also a possibility

- Shipping as liquid hydrogen at pilot scale currently
- Successful pilot tests for LOHC – e.g., methyl cyclohexane ↔ toluene route
- Synthetic methane of interest but not yet commercial (and not necessarily zero carbon)

Source – Bloomberg New Energy Finance – costs include movement, compression and storage

Three focus areas

Supply side

Demand side

Equipment

Demand side

- Japan is focused on building an industry around import and use of hydrogen in the economy
- Japanese government to spend ¥85b (~US$773m) on hydrogen development as part of broader US$4.6bn clean energy transition agenda in FY21/22
- Significant focus on building hydrogen fuel cell vehicles and supporting infrastructure (already has largest network of hydrogen filling stations in the world)
- Intends to procure 300,000 t/year of hydrogen by 2030 and reduce cost of hydrogen from US$18.23 to 3.22 per kg by 2030 and US$2.15 by 2050
- Significant driver of focus is desire to support companies like Toyota, Kawasaki Heavy Industries, Jera, Mitsubishi who are all investing in hydrogen production, shipping and usage technologies
- Local green hydrogen production may be possible with offshore wind

JAPAN IMPORT OPTIONS

Aramco, Institute of Energy Economics and SABIC partnership

- Blue ammonia production in Middle East (advantages with natural gas availability and CCS potential)
- Shipping of ammonia from Middle East to Japan
- Multiple companies exploring ammonia

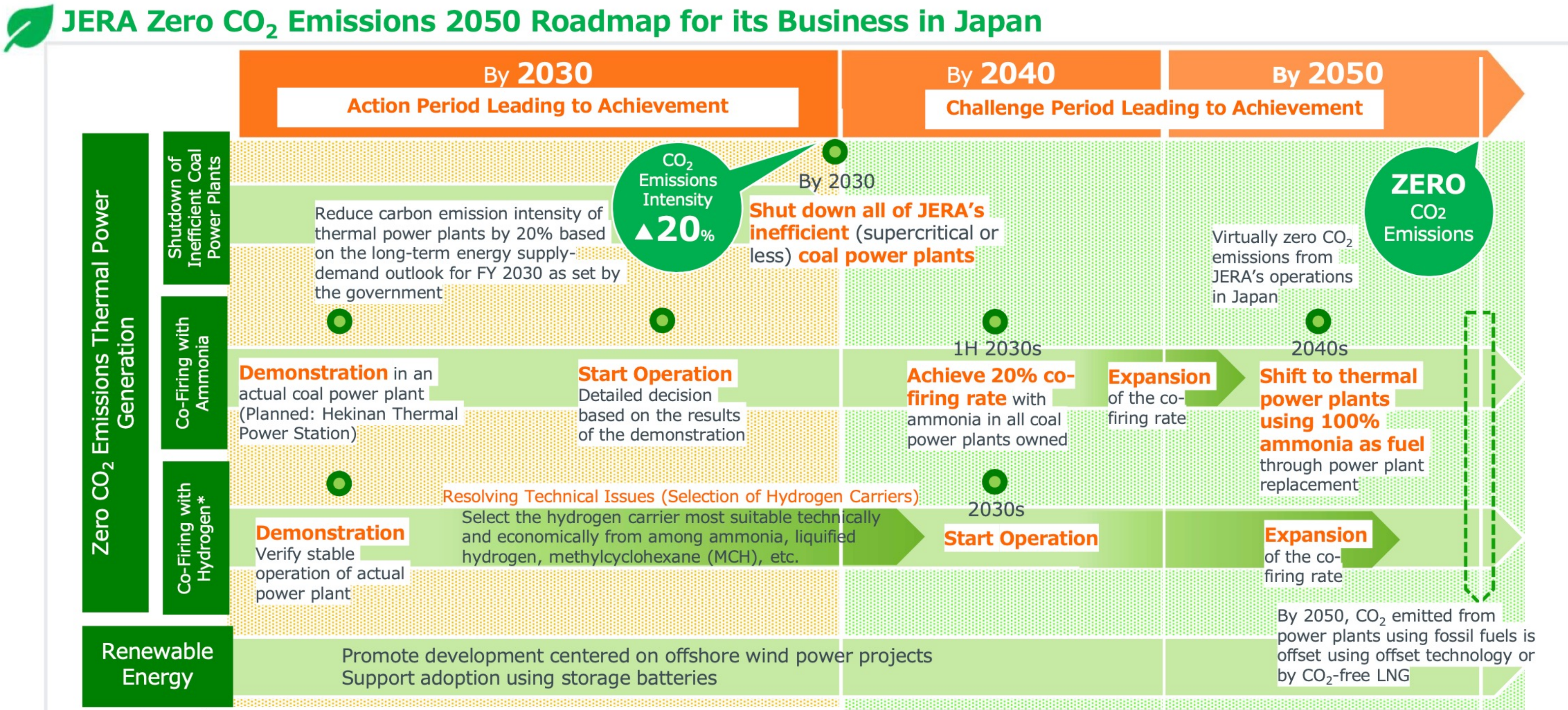
Advanced hydrogen energy chain association for technology development (AHEAD)

- Methyl cyclohexane and toluene route – SPERA by Chiyoda
- Deliveries from Brunei tested via this route
- First shipments in ISO containers rather than a dedicated ship

Hydrogen Energy Supply Chain Technology Research Association (HySTRA)

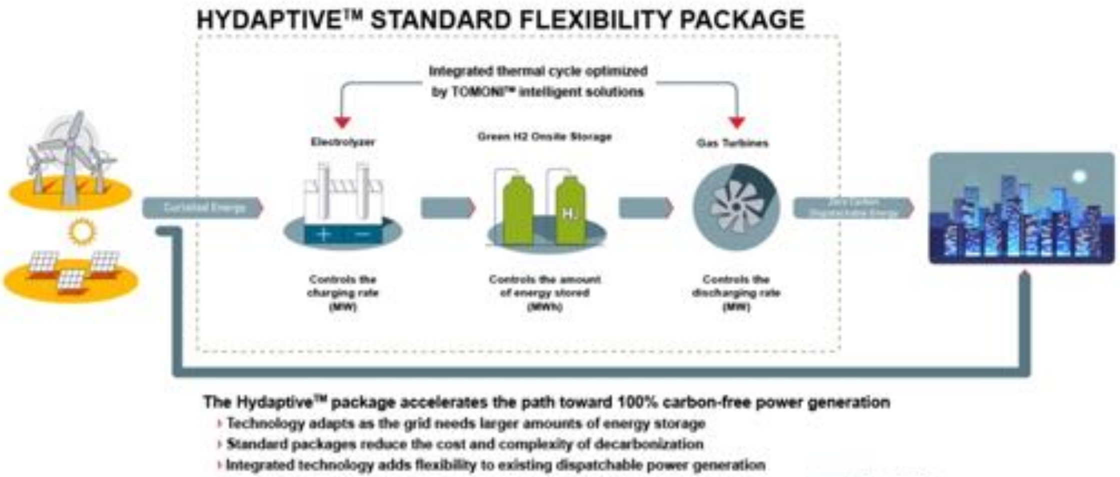
- Shipping of liquid hydrogen from Victoria to Japan
- Hydrogen from brown coal gasification – needs to be CO_2 free so CCS in CarbonNet is necessary
- HySTRA is responsible for gasification, marine transport and unloading (purification, land transport and liquefaction by others)

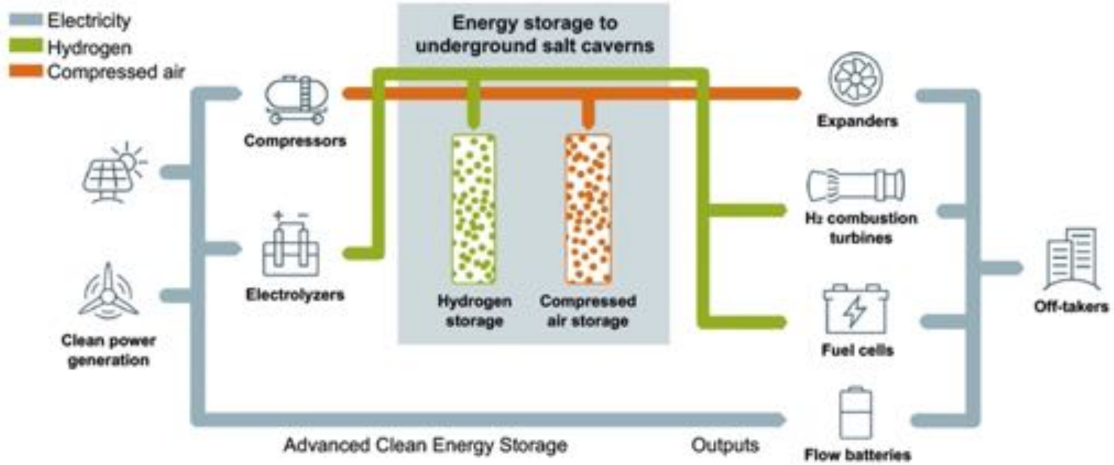
JERA - DRIVING IMPORT OF AMMONIA



This roadmap will be gradually developed in greater detail based on relevant conditions such as government policies. JERA will revise the roadmap when relevant conditions change significantly.
*The use of CO_2-free LNG is also being considered.

MHI - DEVELOPING USE CASES





Three focus areas

Supply side

Demand side

Equipment

EQUIPMENT

Alkaline electrolysers

Summary of key features	
Efficiency	50 – 78 kWh/kg H_2
Installed capacity	37.7 MW
Cost (2020 – stack USD)	$270/kW
TRL	9 - Commercial
Advantages	• Low cost • Common materials • Mature technology

Proton exchange membrane electrolysers

Summary of key features	
Efficiency	50 – 83 kWh/kg H_2
Installed capacity	43.8 MW
Cost (2020 – stack USD)	$400/kW
TRL	9 - Commercial
Advantages	• Flexibility in operations – suited for intermittent energy

Proton exchange membrane electrolysers

Summary of key features	
Efficiency	57 – 69 kWh/kg H_2
Installed capacity	None
Cost (2020 – stack USD)	N/A
TRL	4 – Lab scale
Advantages	• Low operating temperature and pressure • Common materials

Solid oxide electrolysers

Summary of key features	
Efficiency	45 – 55 kWh/kg H_2
Installed capacity	0.5 MW
Cost (2020 – stack USD)	$2,000/kW
TRL	5 - Demonstrated
Advantages	• High efficiency

China - Scale up in production

- China currently has 50% of the world's alkaline electrolysers – expected to scale up production significantly in coming years
- Increased production will likely be in alkaline electrolysers also – in the short term
- Some studies indicate production cost of hydrogen in China will be $1.58/kg from alkaline electrolysers in 2030

Learning rate for electrolysis

Current electrolysers	Cost reductions	Future state

Current electrolysers

- 10 MW largest electrolyser in service
- Some offer electrolysers ~25 MW – but these are made up of multiple, smaller stacks and not yet in service
- 3-4 MW seen as the point at which it is cost effective to have multiple stacks
- ITM and NEL are building 5MW stacks as the basis for large systems

Cost reductions

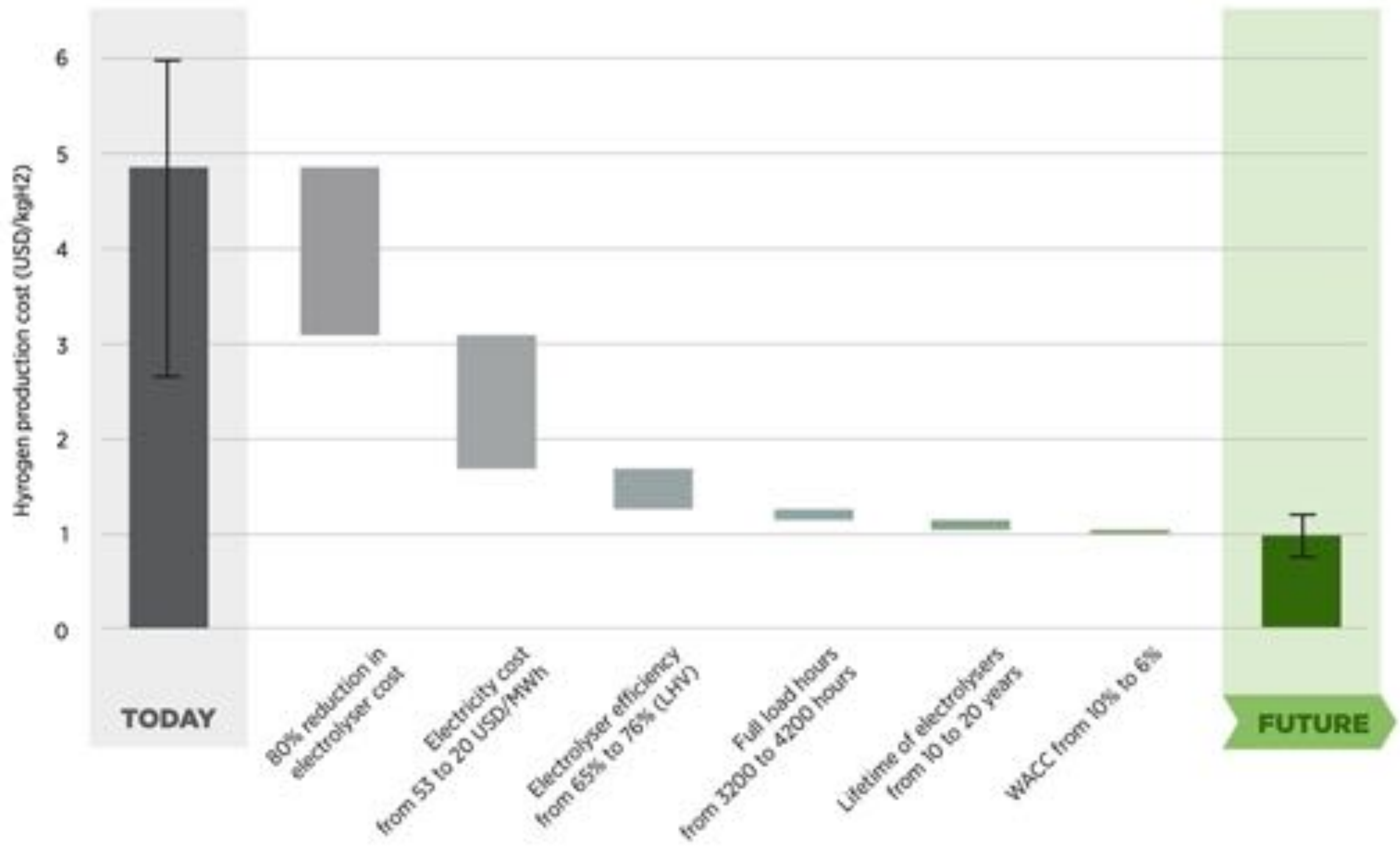
- Materials changes replacing platinum and iridium with other materials potentially
- Critical minerals may be a limiting factor for scale up
- Stack design changes to increase efficiency
- Manufacturing scale and standardisation

Future state

- Learning rate of ~13% forecast for PEM electrolysers – 13% reduction in costs when manufacturing capacity is doubled
  - If manufacturing capacity is 25GW by 2030, capital cost is expected to be 60% of today's levels with this learning rate
- Balance of plant makes up smaller proportion of overall costs at higher stack size – greater economies of scale with compressors etc. as electrolyser stacks are in series
- Planned capacity increases of from 2.1 GW/a (today) to 4.5 GW/a
- IEA expects 25 GW/a needed by 2030 to meet demand

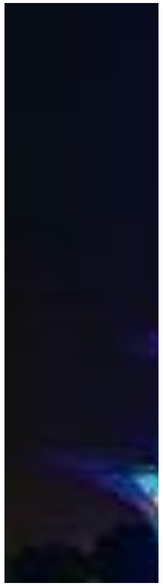
FUTURE GREEN HYDROGEN COSTS

- Large reduction in electrolyser cost required (~80% reduction)
- At 13% learning rate, this implies increase in manufacturing capacity
- Expectation that China will continue to increase manufacturing capacity and extend into PEM electrolysers



CONCLUSIONS

- Hydrogen remains an important part of the decarbonized future – particularly in hard to decarbonize sectors
- Australia has aggressive expansion plans in the export industry – attempt to replicate the LNG industry
- Challenges remain however – especially in transport
- Japan is betting big on hydrogen and ammonia – too early to tell which will win out
- Overall expectation is that hydrogen is locally produced where needed either using renewable energy directly or via RECs
- Costs of green hydrogen need to reduce significantly – blue may be a stepping stone to develop markets and supply chains cost effectively



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